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Citation for published version:

Carter, K 2014, Learning Energy Systems: An holistic approach to low energy behaviour in schools. in *PLEA 2014 Conference Proceedings*. PLEA (Passive and Low Energy Architecture), Ahmedabad, PLEA 2014, Ahmedabad, India, 16/12/14. <http://www.plea2014.in/wp-content/uploads/2014/12/Paper_7C_2912_PR.pdf>

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

PLEA 2014 Conference Proceedings

Publisher Rights Statement:

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LEARNING ENERGY SYSTEMS: An holistic approach to low energy behaviour in schools

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ABSTRACT

Existing buildings are aligned with substantial energy use. Energy modelling is failing to produce an accurate prediction of the energy needed to operate buildings, particularly in the education sector. Schools and higher education estates often use 50% more electrical energy than the design models show. Much of this is associated with what is termed 'unregulated' energy, in other words, energy associated with unpredicted use of the building.

Working with sets of energy data, school pupils, teachers and building managers were involved in an action research project around the theme of lighting energy. This led to a reduction in energy use by lighting of 15%. Lighting control systems and education and awareness of energy use both contributed to this reduction. The study considers the benefits in financial terms. The relatively small gains offer significant potential over the lifespan of a school building. The wider benefit is in the involvement of building users in the management of their energy use.

INTRODUCTION

Understanding the way people use energy is seen as the key to improving energy performance in buildings. This paper presents a pilot study examining an interactive response by school children to the management of lighting in their school. It is part of a wider research project exploring the integration of the 'human' into the energy management of school buildings. The pilot study combined the use of energy data, and lux level measurement with action research in the school building.

It is estimated that lighting for buildings consumes 19% of global electricity generation (Grinfeld and Grinfeld 2009). Improved energy efficiency of lighting has resulted in an overall reduction in this load. UCD-OPET (1994) identifies 12% of energy use for lighting in typical UK schools in the 1990s. This had reduced to 8% in 2012 (Carbon Trust, 2012) due to improved lighting efficiency, however this equates to 20% of the energy costs of the building. This is why it is so important to reduce the amount of energy we use in for lighting (Ryckaert, Lootens, Geldof, & Hanselaer, 2010). Artificial lighting is dependent on electricity and has the highest CO₂ emission factor of energy sources (compared to gas oil and coal) at 0.422 kgCO₂/kWh which further emphasises the need for reducing the energy used for illuminating our buildings (Lee & Guerin, 2010). As well as the cost to the environment, is the cost to society in energy bills. Reducing the energy use of public buildings will reduce the financial burden on local government (Di Stefano 2000).

The amount of energy used for lighting in public buildings is affected by two primary factors: the design of lighting system; and the users of the building and their attitude towards the energy. This study focuses on a primary school building in Scotland, and encompasses an overview of the types of lighting control currently used in existing school buildings. By involving building occupants, the study examines

how these lighting controls can be better used and managed by building occupants to reduce their consumption of electricity, and if modification of building users' behaviour and attitudes towards energy use can reduce the overall energy consumption of the building.

LIGHTING CONTROL

Well designed and controlled lighting systems can reduce the energy use of artificial lighting by up to 40% (Grinfeld and Grinfeld 2009). For optimum energy efficiency a lighting control system must be designed so that it generates the required lux levels, delivering lighting using the least amount of energy (Karlen, Benya, & Spangler, 2012). Control systems have become more sophisticated and range from individual control, to highly sensitive computer operated building systems. This range of systems is found in the school being used for this study.

Local manual switching usually comes in the form of wall switches that can be controlled by building users with on/off or dimming switches (Simpson 2003). Relying on manual switching can lead to a high amount of wasted energy if occupants do not control them efficiently (Rawlinson 2008). Local manual switching is used in the classrooms in the school being studied. Centralised switching can be operated automatically at certain times in the day relating to the operating hours of the building (Wall and Everest 2003). Manual switching is still possible with this system to override automatic settings. If the system is well designed, studies show that few occupants will use the manual override (Grinfeld and Grinfeld 2009). This type of control is used in the corridors and assembly halls of the school but the manual override function is kept locked and can only be operated by the janitors.

Occupancy sensors are used to automatically: turn lights on when a space is occupied; keep lights on while the space is occupied; and turn off the lights once the space is no longer in use (Simpson 2003). The lights will be automatically turned off again after a definable period of inactivity. A Post Occupancy Evaluation (POE) carried out by Buro Happold (engineering consultancy company) on five schools built in the UK between 2002-2005 revealed that the use of PIR sensors saved 30-40% compared to manual switching (Pegg 2009). This study found that general circulation lighting was the worst managed, especially in areas such as atriums. This is due to the space not being 'owned' by anyone, therefore responsibility for the operation of these lights needs to be addressed (Pegg 2009). It is very important for building designers to think about maximising the use of daylighting when designing a building (Loe 2009). Photoelectric lighting controls (daylight linking) can either be an on-off system or a dimming system (Grinfeld and Grinfeld 2009). This type of control is present in the classrooms of the school.

Programme Logic Controllers (PLC) are centralised lighting management systems that control a whole building e.g. a school (Grinfeld and Grinfeld 2009). They consist of a computer based system that can control a combination of presence detection, daylight linking, timed and manually operated lighting systems to provide optimum control, tailored to a specific building and its users needs (Rawlinson 2008). PLCs in conjunction with a mixed manual and automatic control system will use energy most efficiently as long as they are designed to be user friendly (Loe 2009). They are also used in lumen maintenance as a new lighting system may be over specified, therefore it can be dimmed initially and power can be increased over time as the lamps lose light (Grinfeld and Grinfeld 2009) to prolong their life. The school studied has a computerised PLC system (Philips Light Manager) which allows alterations to be made to lights in the school that are controlled by automated PIR, daylight linking and timed systems.

BUILDING OCCUPANT BEHAVIOUR

The behaviour of building users can have a large effect on the amount of energy that the building consumes (Hori, Kondo, Nogata, & Ben, 2013; Masoso & Grobler, 2010). Newborough and Probert (1994) take the strong view that a lack of awareness in how energy is consumed is illiterate and apathetic. Al-Mumin *et al.* (2003) makes a statement that concurs with these views saying that 'energy-unconscious' behaviour of building occupants can lead to an excess in energy consumption. Zografakis (2008) holds the view that young people need to be properly educated on energy saving matters so that our future energy use will be reduced and that the way to do this is the education of students throughout

their school life to instil an 'energy saving culture' (Faiers, Cook, & Neame, 2007; Zografakis, Menegaki, & Tsagarakis, 2008), thus creating a more energy literate society (Newborough & Probert, 1994).

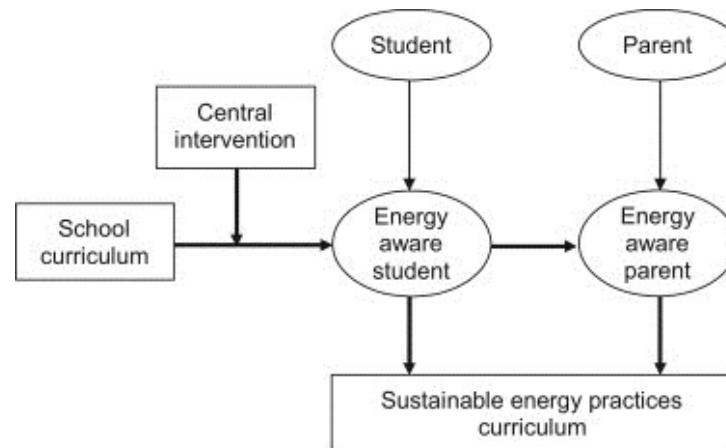


Figure 1: The effects of energy related education in society (Zografakis et al. 2008)

Figure 1 demonstrates how energy education leads to a higher understanding of the need to save energy and encouraging energy efficient behaviour. Although buildings consume the most energy during the day, often the most energy is wasted when the building is unoccupied. This is due to users leaving lights on overnight when they are not needed (Masoso & Grobler, 2010). There is a great need for building occupants to be more energy aware and learn to switch off lights and appliances when they are not being used, to reduce energy wastage (Al-Mumin, Khattab, & Sridhar, 2003; Masoso & Grobler, 2010).

The attitudes and behaviour of building occupants can undermine energy efficient building systems and technology and the two must work in harmony for significant reductions in energy use to be realized (Hori et al., 2013; Masoso & Grobler, 2010). At the same time building designers must gain accurate knowledge of how a building will be used to tailor the design to the users to achieve maximum energy efficiency (Carbon Trust, 2012).

The advantages of behavioural change through education are numerous (Dias, Mattos, & Balestieri, 2004). The potential energy saving could be more than is possible with just energy efficient equipment and systems. It is relatively very cheap and can be applied to any building new or existing (Masoso & Grobler, 2010). They make the argument that to improve energy efficiency; we should concentrate more on improving occupant behaviour and attitudes through education in energy awareness, rather than solely focusing on energy efficient technologies. Many lighting systems in public buildings, such as schools are very complicated. Even with a well designed system, for a building to reach its maximum energy efficiency it is necessary to have energy aware building users (Winterbottom & Wilkins, 2009).

ACTION RESEARCH IN LIGHTING USE

The study involved a group of school children in an action research project associated with lighting in their school. Involving school children in the study helps us see energy use from the eyes of the child. This user group offers a perspective that is often omitted from building management strategies in schools. The opportunity to engage children in the active management of energy use in their schools presents a novel response to the need to reduce energy, and fundamentally, it increases the pool of participants with responsibility for energy use.

Methodology

The research was designed to test two propositions: the behavior and attitudes of staff and pupils at the school will change in response to learning about how lighting uses energy; and that involving building users in the control of the lighting system will lead to a reduction in energy use. Recognition that this was about problem solving, led to an action research approach. This involves interaction to improve the situation, and this pro-active approach offered efficient empirical data collection, vital to the evaluation of the study (Costello, 2011).

The first visit to the school, led by the Facilities Manager, involved quantitative data collection on the lighting system of the school. This included lamps, luminaries and control systems to allow assessment of the energy efficiency of the current lighting system and to see if the hardware and technology could be improved. This was followed by the first phase of the 'lighting use survey'. Another visit to the school, led by the deputy head teacher, enabled qualitative data to be gathered relating to the energy saving attitudes and practices of the school, and an 'energy awareness presentation' to inform the whole school about the lighting study. This was followed by the second phase of the 'lighting use survey'. Figure 2 illustrates the action research process.

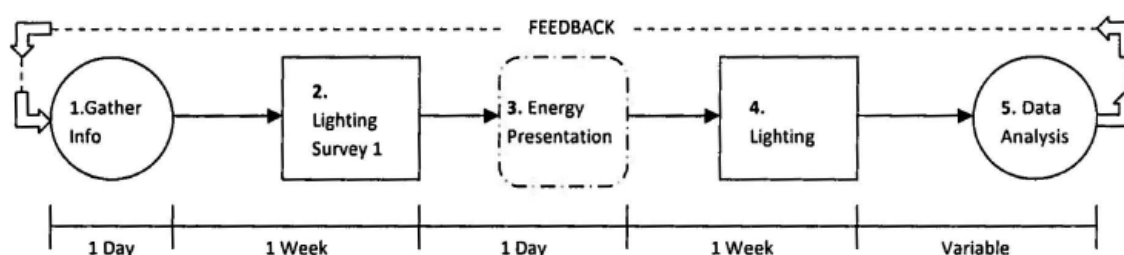


Figure 2: Action Research Process

The action research involved pupil members of the Eco-Committee undertaking the 'lighting use survey' over two separate weeks. Four areas of the school were chosen for the study to capture a range of lighting systems: a general classroom; a science room; the dinner hall; and a shared seating/circulation area. The study was carried out before and after the 'energy awareness presentation' to enable the impact of this session on energy behavior to be gauged. The survey was set up to record three sets of quantitative data:

1. If the lights were on or off at hourly intervals throughout the school day from 9am until 4pm Monday to Friday.
2. If the room was in use during these times.
3. The lux level. (meter placed on table in centre of room, for every reading)

Data from the first phase was used in the 'energy awareness presentation', delivered at a school assembly to all pupils and staff at the school. This provided pupils with information about energy sources both renewable and non-renewable and how we consume this energy. The presentation was designed for primary school children in accordance with advice in the paper '*Energy Education*' by Kandpal & Garg, (1999). Repeating the 'lighting use survey' following the presentation meant that changes in awareness and attitudes to lighting use could be evaluated in terms of actual decreases in lighting use.

Action Research results

Two sets of quantitative data were produced. The first week shows normal lighting usage in the selected areas of the school. The second week demonstrates lighting use after problem solving action in the form of an educational presentation. This allows simple measurement to determine if the change in behaviour of the occupants could have a significant effect on reducing the energy use of the school from

lighting. The four rooms used in the study offer distinct use patterns. The Dinner Hall and Shared Area are used occasionally by large numbers of pupils and are not associated with any particular class group. The Classroom is occupied by the same group of children for the majority of the school week. The Science Room is used occasionally for specific class activities by small groups of pupils led by a teacher.

The action research led to a reduction in energy use from lighting in all areas apart from the Dinner Hall (Figure 3). The graphs show the number of hours that the lights were on and the number of hours that each space was occupied. The significant reduction in energy use is seen in the rooms that are occupied by defined groups (classes). The two large areas with occasional use showed small improvements in redundant use of lighting, and demonstrate the difficulty faced in managing energy consumption in spaces that are not ‘owned’ by their occupiers.

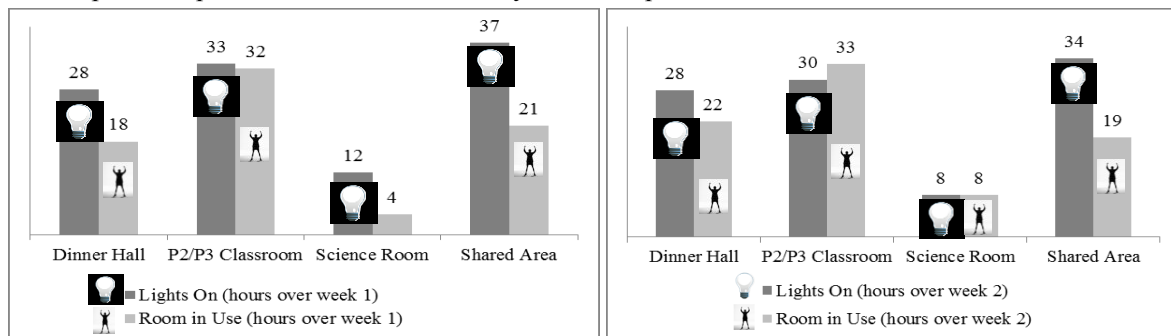


Figure 3: (a) Light and Room Use in Phase 1 (b) Light and Room Use in Phase 2 (numbers represent hours that light is on or room is occupied)

Room Area analysis

The dining area is controlled by a key operated switch box that is kept by the janitors. This meant the energy use could not be directly controlled by the room users. This seems to be linked to energy waste (lighting on in an empty room) at 36% in the first week's study. Redundant light use decreased by 15%. The lighting use was identical over the two weeks but the physical use of the room increased corresponding to an increase in the lighting efficiency (lighting on in a room that is being used) from 64% to 79%, however this cannot be correlated with energy saving behaviour. The lux level was above the recommended 500lux for dining halls in CIBSE (2002) at an average of 770lux during the both weeks of the study. Therefore daylight linking would provide a direct reduction in energy use.

The control system in the classroom is quite advanced as there are three sets of lights. The sets of lights at the window and the corridor side of the classroom are controlled by two daylight sensors at either side of the room. If there is the required lux level of 500lux (CIBSE) then the lights will switch off in that area to save energy. The main on/off switch is located in the classroom and is therefore user controlled. The energy use in this room was very good in the first week's study, 97% of the light was being used and only 3% was being wasted. However in the second week an improvement was made as there was no wastage of light and the room was in use for three hours when the lights were turned off, as daylight would supply the required lux level. The room also used 3 hours less energy in the second week with the similar amount of use. The lighting system is quite advanced. The luminaries are energy saving models with high frequency ballast. However the control system could be improved by the daylight linked lights being dimmed rather than turned completely off. This will save more energy, extend the life of the lamps and be less distracting to room users (Roisin et al. 2008, Li et al. 2010). The average lux level over the two weeks was 510 lux which is very close to the recommended 500lux for classrooms.

The control system in the science classroom is very similar to the P2/3 Classroom as there are three sets of light. The main lighting switch is user controlled. The lighting wastage from this area in the first week was a relatively high at 67%. In the second week 4 hours less lighting the lights were only used when the room was occupied. As with the P2/3 classroom, the lighting system in the science room is

quite advanced. The control system could be improved by the daylight linked lights with a dimming setting as recommended for the P2/3 classroom. The average lux level over the two weeks was 415 lux which is slightly below the recommended 500 lux for classrooms.

The lights in the shared area are controlled on a simple series circuit. These lights are on the same automatic control as corridors, and will be 'held on' as long as lights are on in a room in that area. The overall energy saving in this area over the week was 3 hours but the energy wastage stayed at a high 43%. The lighting system is quite advanced. The luminaries are energy saving models with high frequency ballast. However the control system could be improved by the daylight linked lights as the shared area is located beside two large windows. The average lux level over the two weeks was 554 lux which is much higher than the recommended 200 lux for shared circulation space. This means that the lights could be dimmed to save energy (Li et al. 2009).

Overall in week 1 of the study the four rooms in the study had lights on and the room not occupied for 32% of the time. The use of lighting when not required (i.e. day lighting adequate or room not occupied) reduced by 15% in week 2 of the study.

Cost Analysis

Table 1 shows the savings per week which were calculated by multiplying the power load for the room in watts (electricity use when lights are on) by the by the number of hours the lights were used. This gives an amount of power used in watts which is then divided by 1000 to give an amount in kilowatts. This is a necessary step as a buildings electricity use is measured in kilowatt hours (kWh). The amount of kWh is then multiplied by the unit rate for the school which was at £0.0671 at the time of the study.

Area	Saving from energy education/ week	Saving from dimming lights/week (-20%)	Estimated saving from daylight linking (-15%)	Total combined saving/week
Dining Hall	£0.00	£0.55	£0.41	£0.96
P2/3 Classroom	£0.21	N/A	N/A	£0.21
Science Room	£0.08	N/A	N/A	£0.08
Shared Area	£0.10	£0.22	£0.17	£0.49
Actual Savings	£0.39	£0.77	£0.58	£1.74
Total across school/week	£19.45	£15.40	£11.55	£46.39
Total across school/year	£719.49	£569.63	£427.22	£1,716.34

Table 1: Potential cost savings from lighting efficiencies

The lighting cost was then multiplied by the number of similar rooms or spaces to give a total saving across the whole school campus. This figure was then multiplied by the number of operational school weeks in the year to generate an estimated figure of yearly energy savings. Firstly the estimated yearly energy saving from regular energy awareness presentations is £719.49. This is therefore an effective energy saving measure with a low implementation cost. The lighting system is controlled by Philips Light Manager system which could dim the lights in the appropriate rooms via the computer control system. The lighting savings from dimming the lighting by 20% came in at a lower yearly saving of £569.63 which is possible with the existing lighting infrastructure and is therefore an affordable and feasible energy saving measure. Two out of the four rooms studied could benefit from daylight linking systems as they are located near windows. Although this indicates a decent saving of £427.22, this does not take into account the cost of installation. Therefore with only a small expenditure for energy awareness presentations combined with dimming lights, there is a potential saving of over £1,200 per

year to be made. On top of this, if the daylight linking systems were found to be financially then even more money could be saved on lighting. The cost analysis offers realistic scenarios with commonly used equipment and control systems found in many modern buildings. The installation has a sophistication that offers the ability to respond to the lived experience and feedback on the people using the buildings with small cost implications.

CONCLUSION

Active involvement of building users in the management of buildings is shown to lead to better performing buildings (Bordass & Leaman, 2005). This study has shown engagement with quantitative monitoring, and qualitative education, that direct gains can be made in energy reduction. The focus on lighting provided a tangible and visible energy stream that was measureable and controllable by the project participants. Involvement of school children in this action research is important to embrace the idea of energy communities and their ability to manage energy demand (Fazeli, Christopher, Johnson, Gillott, & Sumner, 2011). The reduction in lighting use experienced in this study, seems to be linked to feedback data on lighting use, combined with an educational presentation on energy.

These results show that there is a large scope for energy saving through different aspects of lighting control. This can be done by either changing how the lighting operates using the PLC or changing how the lighting is operated by changing the behaviour and attitudes of the building occupants. It also highlights that there is little or no energy savings to be made by upgrading lamps and ballasts at the moment as the school has very up to date technology.

The study provides useful insights into the effectiveness of including people in the management of complex energy systems. Modern energy infrastructure is increasingly relying on complex building management systems (BMS) to monitor and control systems. In the study building a sophisticated lighting control system is installed. The way in which it has been set up does not relate to the way in which the building is being used. The involvement of building occupants in their environment offers potential for improving the way that complex systems can operate and respond to the lived experience of these people.

This study is part of a larger project, Learning Energy Systems at the University of Edinburgh, currently exploring methods to better integrate building occupants into the management of energy in their school buildings. This study demonstrates that with small interventions, significant energy reduction is possible over the life span of a building by addressing user behavior. In this case 15% reduction in lighting use was achieved with minimal intervention or alteration to the lighting control system. This potential this offers to a wider range of energy use beyond lighting in school buildings is considerable, and this provides interesting context for further work in this area.

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